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Determination of relative tectonic activity of the Honaz fault (SW Turkey) using geomorphic indices

Jeomorfik indisler kullanılarak honaz fayı'nın (GB Türkiye) göreceli tektonik aktivitesinin belirlenmesi

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Abstract

In this study, in order to determine relative tectonic activity of the Honaz Fault, geomorphic indices such as triangular facets, drainage basin asymmetry (AF), hypsometric integral (HI), drainage basin shape (Bs), ratio of valley-floor width to valley height (Vf), and mountain front sinuosity (Smf) have been calculated. The results of the indice analysis were evaluated and then index of the relative tectonic activity (Iat) were re-evaluated. Base on the different Iat values, the results were divided into four classes that range from the relatively highest to the relatively lowest tectonic activity. The drainage basin area between Honaz Fault and Mount Honaz is an ideal place to test relative tectonic activity. The Honaz fault that is the north boundary fault of the Honaz Mountain has been divided into the Karateke segment and Honaz segment. The indice values calculated from these segments are triangular facets (Lf / Ls: 0.3-0.46), AF (32-77), HI (0.1-0.6), Vf (0.08-0.7), Bs (1.53-5.06) and Smf (1.12-1.41). The results of this study exhibit the presence of high to very high tectonic activity especially in the central part of the Honaz Fault. Based the results, the neotectonics played an important role in geomorphic evolution of this part of the Honaz Mountain. In addition to the results obtained, evidence of seismic activity, travertine occurrences due to thermal springs and alluvial fans in front of fault zones support high tectonic activity in the region.

Keywords: Honaz fault, Tectonic geomorphology, Relative tectonic activity, Geomorphic indices, Western Anatolian

Öz

Bu çalışmada, Honaz fayının göreceli tektonik aktivitesinin belirlenmesi için, dağ önü sinüslülük oranı (Smf), üçgen yüzler, vadi taban genişliğinin vadi yüksekliğine oranı (Vf), drenaj havzası asimetrisi (AF), hipsometrik integral (HI) ve drenaj havzası şekli (Bs) gibi jeomorfik indisler hesaplanmıştır. İndis analizlerinin sonuçları değerlendirilmiş ve daha sonra göreceli tektonik aktivite indisi (Iat) olarak tekrar değerlendirme yapılmıştır. Farklı Iat değerlerine dayanarak, sonuçları nispeten en düşükten en yüksek tektonik aktiviteye kadar dört sınıfa bölünmüştür. Honaz Fayı ile Honaz Dağı arasındaki drenaj havzası alanı, göreceli tektonik aktiviteyi test etmek için ideal bir yerdir. Honaz Dağı'nın kuzey sınır fayı olan Honaz fayı morfolojik olarak Karateke ve Honaz segmentlerine ayrılmıştır. Bu iki segmentte hesaplanan indis değerleri, Smf (1.12-1.41), üçgen yüzeyler (Lf/Ls: 0.3-0.46), Vf (0.08-0.7), AF (32-77), HI (0.1-0.6) ve Bs (1.53-5.06)'dır. Bu çalışmanın sonuçları Honaz Fayının özellikle orta kesimlerinde çok yüksek ve yüksek tektonik aktivitenin varlığını ortaya koymaktadır. Araştırmanın sonucu, Honaz Dağı'nın bu bölümünün jeomorfik evriminde neotektonizmanın önemli bir rol oynadığını göstermektedir. Elde edilen sonuçların yanı sıra bölgedeki sismik aktivite, sıcak su kaynaklarına bağlı traverten oluşumları ve fay hatlarının önündeki alüvyon yelpazelerinin varlığı bölgedeki yüksek tektonik aktiviteyi desteklemektedir.

Anahtar kelimeler: Honaz fayı, Tektonik jeomorfoloji, Göreceli tektonik aktivite, Jeomorfik indis, Güneybatı Anadolu

1 Introduction

Geomorphology is a significant tool in tectonic studies when using the geomorphic record. Such record includes several landforms and Quaternary deposits that capture immense amount of information from the last few thousand years and may go back approximately more than two million years [1]. Tectonic geomorphology focuses on the contrast between topography and geomorphologic features generated by tectonic activity and the erosional factors caused by surface processes that tend to modify them. Defining the relationship between these processes and interpreting the resulting landscape variations are the main interest of tectonic geomorphology [2]-[3]. The study of landscapes, and surface processes including their description, classification, origin, development, and history, that emphasize the physical, biological, and chemical aspects, is regarded as geomorphology. It may either have a qualitative or a quantitative representation. The quantitative measurement of landscape is based on the calculation of geomorphic indices using topographic maps or digital elevation models (DEM), aerial photographs or satellite images, and fieldwork [1].

The close relationship between morphometric indices and tectonics has been introduced in earlier studies and certain classifications were developed [4]-[7].

In regions under active extensional tectonics, (e.g. as in Aegean province, normal faults, which are divided into segments, are characteristic and shed light landscape evolution [8]-[9]. The Honaz Fault, which is interest in this study, is a normal dip slip fault in western Turkey has been investigated in two segments: the Karateke and Honaz segment (Figure 1). Similar geomorphological studies segment have been carried out both on normal and strike-slip fault systems [10]-[15].

In the study performed by [14], tectonic evaluations have been made using geomophic indices. In this article, relative tectonic activity indice (Iat) in addition to [14]. This indice, proposed by [7], was obtained by taking statistical averages of all the results that were yielded. The Iat indice results have also been studied and discussed to determine the level of tectonic activity by dividing into different ranges. The results obtained from the

Karateke and Honaz segments forming the Honaz fault show that these two segments have given different geomorphological results and different relative tectonic activity.

The aim of this study is to identify tectonic and morphological features by using morphometric indices calculated for a mountain front that is bounded by the Honaz Fault and drainage areas between the fault and northern slope of the adjacent Honaz Mountain (Figure 1). In addition, indices calculated have been classified in accordance with the tectonic activity classification suggested by [7].

2 Regional geology and tectonics

The Denizli extensional basin is one of the well-known depression in Western Turkey, located at the intersection of the Gediz and Büyük Menderes grabens [16]-[20]. The NW trended Denizli basin is bounded by the Pamukkale fault in the North and Babadağ and Honaz Faults in the south. The Honaz Fault bounds the northern part of the Honaz Mountain, which is the highest one in the Aegean region with an elevation of 2571 meters. The fault has a total length of 13 km and has been studied in two segments. The first segment is situated in the west and is Karateke segment [21]. The second one called an Honaz segment is situated to the east (Figure 1b).

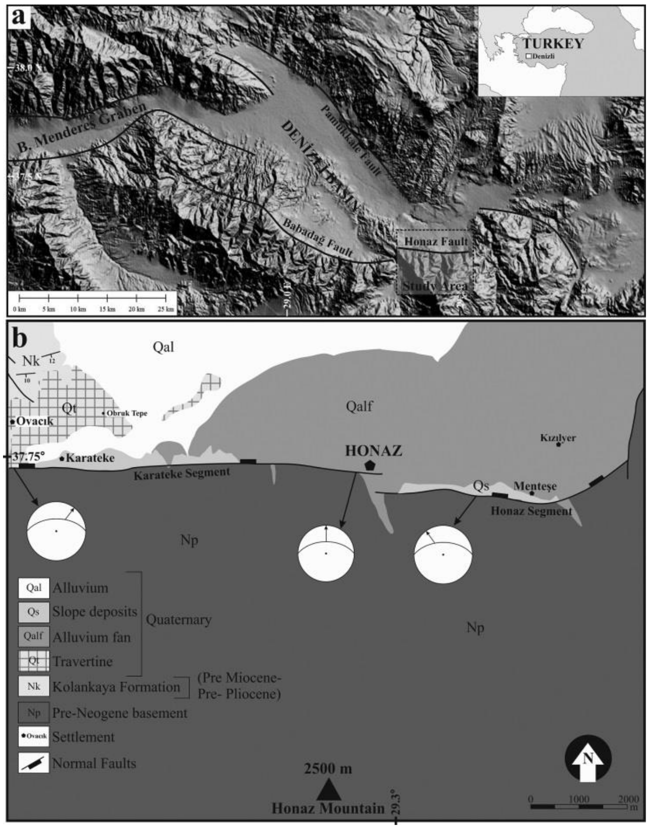


Figure 1: (a): Tectonic outline of the Denizli Basin and location of the study area. (b): Simplified geological map of the Honaz Fault [22].

At the footwall of the Honaz Fault, metasediments, Mesozoic allochthonous units of Lycian Nappes such as ophiolite, limestone, dolomite, and gypsum are exposed [23]-[24]. They are allochtonous, and are imbricated and thrusted internally. The gypsum beds are black to dark gray in color. Their measurable thickness is about 300 m and the beds were intensely deformed and folded [23]-[24]. According to 87Sr/86Sr data that ranges between 0.707761 and 0.707772. [24], obtained a Late Triassic age from the gypsum exposure that intercalates with dolomite at the south of Kızılyer (Figure 1b). The age of the successions, overlying these metamorphics, i.e. known as the Honaz Shale, ranges, in general, from Triassic to Paleocene [25]. The Honaz Shale, take places at footwall of the fault, consists of low grade metamorphic rocks such as phyllite, slate and calcschist [21]. N-S trending folded structures have been developed within the metamorphic rocks and resulted from compressional tectonics [26]. Possible age of the metamorphic units was given as Upper Paleozoic by [25] which correlates with the uppermost levels of the Menderes massif. The ophiolitic unit, usually composed of harzburgite, serpentinite, gabro-diabase dykes, crops out in the southeast part of the Honaz Mountain [26]. The ophiolitic units that overthrusted the Eocene-Oligocene units are unconformably covered by late Miocene-late Pliocene units [27]. A Mesozoic allochtonous overlies the metamorphics carbonate succession and has been imbricated and thrusted internally. Age of this succession is Triassic-Paleocene [25]. The gypsum beds are black to dark gray in color, their measurable thickness is about 300 m. and the beds were deformed and folded intensely [23]-[25]. At the hanging wall of the Honaz Fault, the late Miocene to late Pliocene deposits of fluvio-lacustrine origin and alluvium, alluvial fans, slope debris and travertines of Quaternary age exposed [19]-[27]. The Quaternary deposits rest on the late Miocene-late Pliocene sediments with an angular unconformity (Figure 1b, Figure 3).

3 Tectonic outlines of the Honaz fault

The Honaz Fault, one of the southern boundary faults of the Denizli Basin and still active, has generated earthquakes that are recorded in historical and instrumental periods [22]-[28]-29]. The fault is approximately E-W oriented and has a length of 13 km totally. The first segment, observed between Karateke and Honaz is 7 km long and named as 'Karateke fault' [21] (Figure 1b). The second one, passing through the town of Honaz, extends toward the Kızılyer village to the east (Figure 1b). The fault planes on the Honaz segment of 6 km long are very obvious (Figure 1b).

The fault planes observed on the Honaz segment are E-W trending and their dips are oriented to the north and range between 40° and 60°. Fault breccia and signs of oxidation along the Karateke segment have been observed and dip of the fault plane varies from 71° to 88° (Figure 2).

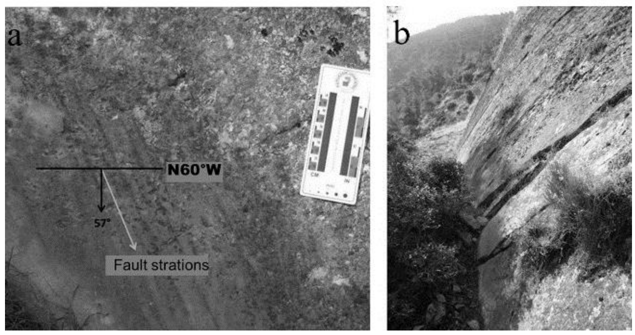


Figure 2: (a): Fault plane and slickenlines, measured on the Honaz fault segment, showing a lateral strike-slip component (b): General trend of Honaz Fault (between Honaz and Menteşe, see Figure 1b for location).

Fault planes have been measured by vertical component at the centrum of Honaz, right-lateral component at the south of Ovacık and left-lateral component to the west of Menteşe village (Figure 1b). Extensive alluvial fans developed along west of the fault. Looking at historical and recent earthquakes, the Honaz Fault is still active seismically [29]. In a study performed by [28], the calculated amount of the Honaz Fault was 121 meters in a southern direction. Consequently, this situation explains why the alluvial fans cover extensive areas. In addition, several warm thermal spring waters emerged along the Karateke segment in the west, rich in calcium bicarbonate, precipitated travertine-tufa deposits [19]-[30].

Based on the historical and instrumental earthquake records, the Denizli basin has a moderate seismic activity with magnitude up to 6.0 [31]. For instance, the ancient city of Hierapolis at Pamukkale, located along the northern boundary fault (called as Pamukkale fault segment) of the Denizli Basin, was damaged several times by the earthquakes [32]-[33]. Normal faulting, which has a small amount of strike-slip component, is widespread along these boundary faults [34]. Most of the earthquakes occurred in the basin have focal depths of 5 to 15 km [35]. According to seismic records of the instrumental period, the magnitude of the biggest earthquake that occurred along the Honaz fault zone was measured as Ms=5.7 and occurred on June 13, 1965. The last event with magnitude Ms=5.2 occurred on April 21, 2000 on the same fault zone [36].

4 Method

Geomorphic indices are very useful materials to determine the relative tectonic activity in a region. In this study, geomorphic indices were calculated to determine the relative tectonic activity of the Honaz Fault. In these calculations, 6 main parameters such an Smf, percentage faceting, Vf, AF, HI, and Bs, were taken into account. Geomorphic indices, formulas and descriptions that used in this study were given in Table 1. The DEM data with a resolution of 10 m have been used in order to calculate the geomorphic indices obtained from the maps of 1/25000 scale. The DEM data were processed and the calculations were made using Mapinfo, ArcGis and Global Mapper GIS-programs.

In addition, it has been checked by the Kolmogorov-Smirnov (K-S) test if statistical differences are present in the HI values that were calculated in the valleys bounded by the Honaz segment and Karateke segment. All the results provided from the geomorphic indices were statistically evaluated considering the index of relative active tectonic (Iat) proposed by [7].

5 Results

Geomophic indices are frequently used to determine both topographic analysis and relative tectonic activity. Different indices are used during the analysis of mountain fronts and drainage areas. Indices used for the active tectonics could determine the different anomalies along the mountain fronts and drainage areas. These anomalies could have been resulted from local tectonic activity, uplift or subsidence. The indice values yielded were used in order to analyze the drainage areas between the Honaz Mountain and the Honaz Fault. and to divide into tectonic classes based on the value intervals of the indices. In consequence, the calculated indices were collected, averaged, and used for classification of the relative tectonic activity in the study area.

5.1 Mountain front

For determining the geomorphology of the mountain, at the northern part of the Honaz Mountain, mountain front sinuosity and triangular facets were calculated along the segments of Karateke and Honaz (Figure 3).

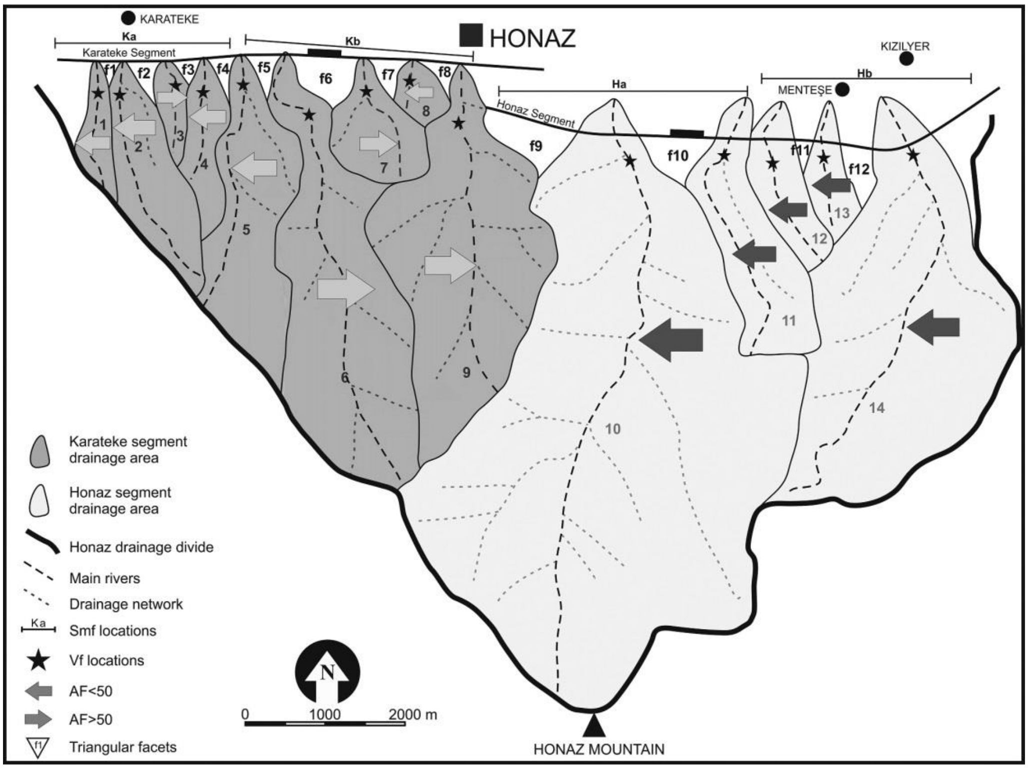
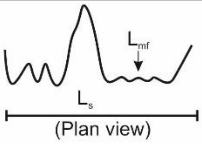
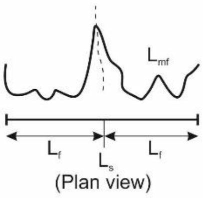
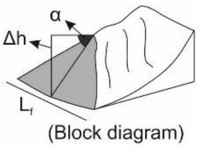
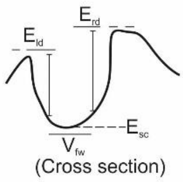
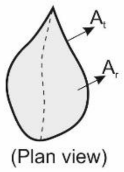
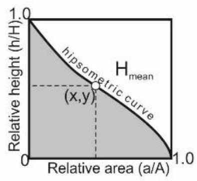
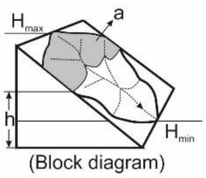
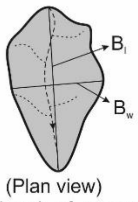


Figure 3: A schematic map that displays the main geomorphic indices calculated in this work.

Table 1. Morphometric parameters used in tectonic landscape analysis of Honaz Fault (modified from [37].

Morphometric parameter	Mathematical derivation	Measurement procedure	Explanation	Source
S_{mf} mountain front sinuosity	$S_{mf} = L_{mf}/L_s$		S_{mf} :1.1 – high tectonic activity S_{mf} :1.1-1.5 – moderate tectonic activity S_{mf} > 1.5 – low tectonic activity	[1]-[4]-[6]-[7]-[37]-[38]-[40]
Facets: Percentage faceting	L_f/L_s		Tectonically active fronts display prominent, large facets that are generated and/or maintainedby recurrent faulting along the base of the escarpments, i.e. high percentage faceting	[6]-[40]
Facets: Facet slope to height ratio	$\alpha/\Delta h$		Tectonically active fronts display higher values of facet slope, height, length and smaller values of facet slope to height ratio	[41]
Vf, valley floor width-to-height ratio	Vf=2Vfw / [(Eld−Esc)+(Erd−Esc)]		The index reflects differences between broad-floored canyons with relatively high values of Vf, and V-shaped canyons with relatively low Vf values	[4]
AF, asymmetry factor	AF=100(Ar/At)		The index was determined to detect tectonic tilting transverse to the flow at drainage basins	[1]-[42]-[43]
HI, Hypsometric integral and Hypsometric curve	x=a/A y=h/H		Convex hypsometric curves characterise relatively 'young' weakly eroded regions, S-shaped curves characterise moderately eroded regions, and concave curves characterise relatively 'old' highly eroded regions	[1]-[6]-[40]
	$HI=(h_{mean}-h_{min})/(h_{max}-h_{min})$		Higher values of HI indicate that most of the topography is high relative to the mean. Intermediate (straight or S-shaped curves) to low (upwardly concave curves) values are associated with more evenly dissected drainage basins	[1]
B_s, Drainage Basin Shape	$B_s = B_l/B_w$		Bs > 4 high tectonic activity Bs: 4-3 moderate tectonic activity Bs < 3 low tectonic activity	[7]

*symbols: Smf: mountain front sinuosity, Lmf: length of mountain front along the mountain–piedmont junction, Ls: straight-line length of the front, Lf: cumulative facets length, Δh: local relief between the scarp base and the upper vertex of the triangle, α: slope of the triangle's altitude measured between the base and the vertex, Vf: valley floor width-to-height ratio, Vfw: valley floor width, Eld and Erd: respective elevations of the left and right valley divides, Esc: elevation of the valley floor, AF: asymmetry factor, Ar: area of the basin to the right (facing downstream) of the trunk stream, At: total area of the drainage basin, x and y: axes, a: surface area within the basin above a given line of elevation, A: total surface area of the basin, h: given line of elevation, H: total height, HI: hypsometric integral, Hmean: mean elevation, Hmin: minimum elevation, Hmax: maximum elevation, H: the difference between the water surface elevation at the defined upstream and downstream locations, Bs: drainage basin shape, Bl: length of the basin, Bw: width of the basin.

5.1.1 Mountain front sinuosity (Smf)

In four different areas, the mountain fronts have been calculated along the Karateke and Honaz segments for the north of the Honaz Mountain. According to these calculations, the smf values range from 1.12 to 1.41 (Figure 3) (Table 2).

5.1.2 Triangular facets

Twelve triangular facets were calculated for the areas restricted by the Karateke and Honaz segments. Average slope dip and height are calculated as 22.07° and 285.3 m, respectively. Among the data calculated, facet 13 is 1200 m high and facet 12 has the highest dip value. Average dip-height ratios are 0.11 for the Karateke segment, and 0.06 for the Honaz segment. Widths of the triangular facets are between 350-1050m with an average of 732.6 m.

5.2 Drainage system of the Honaz mountain

Drainage system of the Honaz Mountain consists of drainage areas, each ranging up to 20 km^2 spatially. In general, flow directions of the main streams were developed perpendicular to the Honaz Fault. Maximum flow lengths of the streams in the drainage areas, shown in dashed lines in Figure 3, change between 1 and 8 km. All the streams are ephemeral except one i.e. drainage area 10. Drainage areas located in the central part of the Honaz Fault are bigger than those at the margins (Figure 3).

5.2.1 Valley floor width-to-height ratio (Vf)

In order to determine the Vf index, calculations have been carried out, 200m up valley in the small valleys, 500m up valley in the large valleys, with respect to the fault. In the calculations carried out along the Honaz Fault, the Vf values are 0.08-0.7. Large values (>0.2) of Vf were calculated in the drainage areas of 1. 2. 3. 4. 5. 6. 7. 8. 11 and 14 whereas small values were calculated in the drainage areas of 9. 10. 12 and 13 (Figure 3) (Table 3).

Table 2: Smf and Lf/Ls values for the mountain front which are bounded by Karateke and Honaz segments. For each main front, the mean values are also indicated.

Segment	S_{mf}	Mean S_{mf}	L_f/L_s	Mean L_f/L_s
Karateke	1.12	1.14	0.3	0.38
	1.16		0.46	
Honaz	1.25	1.33	0.23	0.33
	1.41		0.44	

Table 3. Morphometric data and tectonic activity class in the study area.

Segment	Drainage basin	S_{mf}	Class of Smf	V_f	Class of V_f	AF (50-AF)	Class of AF	Hi	Class of Hi	Facet slope to height ratio	B_s	Class of B_s
Karateke	1	1.045	1	0.66	2	72 (-22)	1	0.51	1	0.22	3.97	2
	2	1.006	1	0.46	1	76 (-26)	1	0.45	2	0.1	4.30	1
	3	1.053	1	0.44	1	48 (2)	3	0.2	3	0.18	5.61	1
	4	1.06	1	0.7	2	63 (13)	2	0.1	3	0.08	2.97	3
	5	1.04	1	0.21	1	77 (-27)	1	0,2	3	0.1	4.87	1
	6	1.005	1	0.61	2	49 (1)	3	0.6	1	0.06	5.06	1
	7	1.036	1	0.31	1	32 (18)	1	0.2	3	0.1	1.53	3
	8	1.048	1	0.57	2	76 (-26)	1	0.51	1	0.1	2.33	3
	9	1.174	2	0.08	1	43 (7)	2	0.51	1	0.05	2.59	3
Honaz	10	1.088	1	0.09	1	57 (-7)	2	0.6	1	0.11	2.44	3
	11	1.036	1	0.58	2	69 (-19)	1	0.51	1	0.04	4.48	1
	12	1.064	1	0.1	1	54 (-4)	3	0.3	3	0.13	2.77	3
	13	1.046	1	0.19	1	60 (-10)	2	0.2	3	0.05	3.10	2
	14	1.75	3	0.51	2	54 (-4)	3	0.3	3	0.03	2.06	3

5.2.2 Asymmetry factor (AF)

At the northern part of the Honaz Mountain, the AF indices were calculated for drainage networks located on the footwall of the fault. Tilting directions of the drainage areas have been shown based on the calculated values, which are larger or smaller than 50 (e.g., AF>50: dip to W, AF<50: dip to E) (Table 3).

5.2.3 Hypsometric curve and hypsometric integral (Hi)

Hypsometric integrals were calculated and hypsometric curves were drawn for 14 different drainage areas located on the footwall of the Honaz Fault. The Hi values, calculated on 9 different drainage areas on the footwall of the Karateke segment area are 0.1-0.6, whereas the Hi values are 0.2-0.6 for 5 drainage areas on the footwall of the Honaz segment. High Hi values at the drainage areas of the region generally form convex hypsometric curves, while the moderate and low values represent S-shaped and smooth curves (Figure 4).

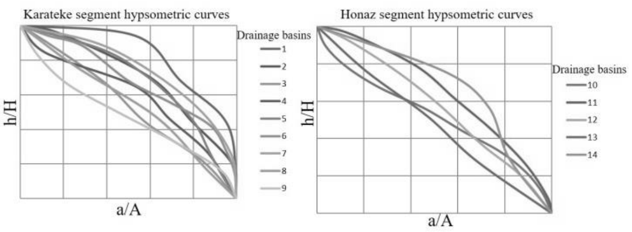


Figure 4: Hypsometric curves for the drainage basins that were bounded by Karateke and Honaz segments.

According to a Kolmogorov-Smirnov (K-S) test, there is no significant difference in Hi values which are calculated from the areas of Karateke and Honaz segments (Figure 5). The presence of high Hi values, along two segments indicates that these areas are relatively young and weakly eroded.

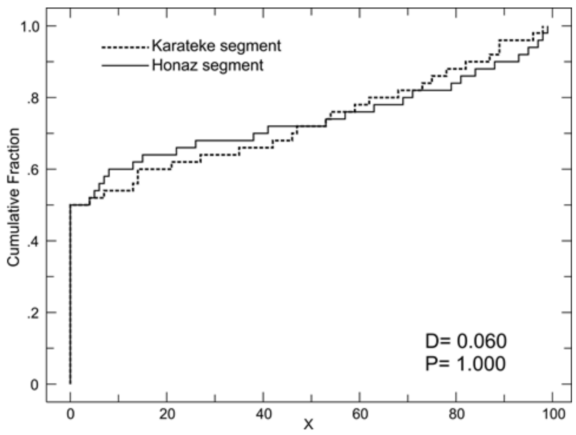


Figure 5: Kolmogorov-Smirnov (K-S) test results of the hypsometric integral values of Karateke and Honaz segments.

5.2.4 Shape of the drainage basins (Bs)

The Bs index was calculated for 14 drainage areas. The Bs values vary between 1.37 and 5. The highest Bs values have been observed in the drainage area 6 and 11 (Table 3).

6 Discussions

Various authors differentiated tectonic activities of the certain regions in different tectonic classes using geomorphic indices. Based on Smf values, [7], separated tectonic activity in three different classes: class I (Smf<1.1), class II (1.1≤Smf<1.5), and class III (Smf≥1.5) (Table 3). Smf values <1.4 indicate tectonically active mountain fronts [5]-[38]. Higher Smf values (<3) are related to inactive mountain fronts. Whereas mountain fronts related to active uplift have relatively smooth and low Smf values, Smf values of 1.4-3.0 and 1.8-5 correspond to low active and inactive regions, respectively. In case of a low or a completely stopped uplift ratio, erosional processes start and form sinuous mountain fronts that are smoothed in time [38]. According to [6], linear mountain fronts have Smf values <1.5 and reflect basic geomorphic and structural characteristics of tectonically active terrains (class I).

Whereas, irregular mountain fronts, in which Smf values vary between 1.8 and 2.3, represent the regions of class II.

The Smf values that have been calculated for the study area, are approximately 1.14 for the Karateke segment and 1.33 for the Honaz segment. In the Smf calculations for each valley in the study area, apart from valley 9 and 14, the values are lower than 1.1, corresponding to class I of [7]. These values display that the area is significantly active in aspect of tectonic.

Along tectonically active mountain fronts, clear and large triangle surfaces are seen. In tectonically less active regions, on the other hand, small and uncertain triangle surfaces develop [2]. When the triangle facets are compared, those on the Honaz segment are wider and more certain than those on the Karateke segment. This case indicates that the Honaz segment is more active in tectonic.

In the narrow and deeply incised valleys, Vf values are small and related to uplifting [1]. [7] divided the Vf values into three classes: class I:Vf≤0.5; class II:0.5≤Vf<1.0 and class III:Vf≥1. According to [39], V-shaped valleys (Vf<0.6) point out active incision, in contrast U- shaped valleys (Vf: 0.3-0.80) indicate valley bottom filling. The low Vf values calculated from the study area imply that the drainage network is V-shaped, which is indicative of deeply incised valleys. Based on these data, tectonic activity has encouraged the valley development accompanying by uplifting in the region.

In development of basin asymmetry, structural control of the cleavage orientation of or bedding could play an important role [7]. Inclination of cleavage or bedding preferably enables the valleys to migrate in the down-dip direction, generating an asymmetric valley. Therefore, these values, which have been obviously influenced from the rock structures, should be disregarded. Depending on the classification scheme of [7], |AF-50|>15, |AF-50|=7-15 and |AF-50|<7 values indicate that high-, medium- and low tectonic activity, respectively. Based on the AF values in the study area, tilting of the Honaz segment is oriented towards the west, in contrast, there is an irregularity along the Karateke segment.

Low values of Bs indicate a more circular basin in shape, usually accompanied by low tectonic activity. Rapidly uplifted mountain fronts cause elongated, steep basins; and when tectonic activity is diminished or stopped, widening of the basins happens that start from the mountain front [7]-[37]. In their study, [7] proposed three different tectonic classes using the Bs values.

In this classification, Bs values of >4 are usually accompanied by relatively higher tectonic activity (class I), Bs values of 4-3 are have been assigned to medial tectonic activity (class II), and

Bs values of <3 were regarded as a result of low tectonic activity (class III).

Looking at the Bs values of the studied area, the highest values, corresponding to higher tectonic activity, have been measured in the areas 1, 6 and 11 (Figure 3). Low and moderate values for the other areas indicates a circular drainage area pattern. The circular drainage pattern shows that there is no very fast uplift in this region.

7 Discussion of relative tectonic activity based on geomorphic indices

In this study, the method proposed by [7] was used to assessment the index values over the studied area that represents the relative tectonic activity (Iat). We divide the various indices into three classes, with class one reflecting high tectonic activity and class three representing low activity (Table 3). The Iat was obtained by averaging the different classes of geomorphic indices S/n (S: total of class of indices results, n: total indices number) and divide them into four classes, in which class 1 corresponds to a very high tectonic activity with values of S/n ranging between 1 and 1.5; class 2 to a high tectonic activity with values of S/n>1.5 but < 2; class 3 to moderately tectonic activity with S/n>2 but <2.5; and class 4 to a low tectonic activity with values of S/n>2.5.

The average of the indices S/n and Iat values that are used in active tectonics and that are measured for 14 drainage areas of the study area (see Figure 3 for basin locations) have been summarized in Table 4. From the obtained Iat values, the areas have been designated to show a relative tectonic activity (Figure 6).

Based on the Iat classification for an area of 55.03 km^2, Iat class 1 is very high relative tectonic activity with a value of 19.8% (10.9 km^2), Iat class 2 is high relative tectonic activity with a value of 61.6 % (33.9 km^2), Iat class 3 is moderate tectonic activity with a value of 3 to 2.8 % (1.6 km^2) and Iat class 4 is low tectonic activity with a value of 15.8 % (8.7 km^2) (Figure 6).

The Iat calculated for the study area amounts 81.4%. This corresponds to a high to very high tectonic activity. The areas with highest values correspond to the middle parts of the Honaz Fault. Consequently, the middle part this normal fault has greater dip-slip.

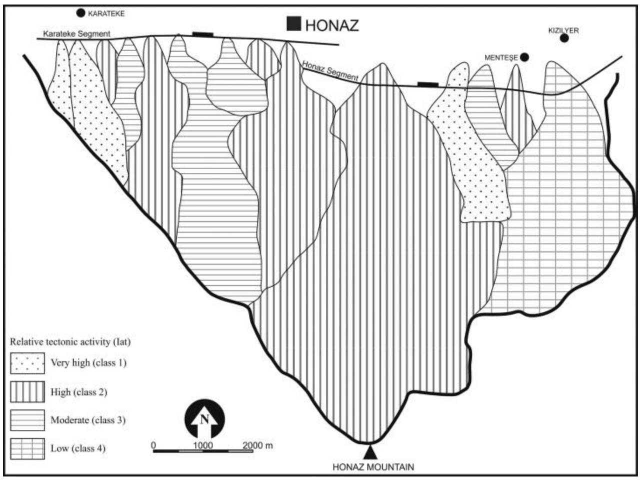


Figure 6: Distribution of the Iat index of relative active tectonics in the study area.

In different tectonic terrains where great rates of active tectonics are evident, values of indices are different as well as their ranges. Iat values also differ as in boundaries between classes of relative tectonic activity [7]-[44]-[46]. Morfotectonic indices are related to several parameters such as tectonic processes, climate conditions, lithology and size of catchment area [1]. In classification of relative tectonic activity (Iat), selection of these indices could be preferential. Indices of active tectonics may determine anomalies in fluvial systems or mountain fronts. These anomalies may be resulted from local variations that result from tectonic activity due to uplift and subsidence [7]. Assessment of active tectonics by field observations matches well geomorphic indices and Iat values.

In fact, classes 1 and 2 of Iat correspond to the fields that have fault scarps, active mountain fronts, triangle facets, steep hanged valleys, deformed alluvial deposits and deeply incised river valleys along the Honaz Mountain (Figure 6). In Iat indice map of this study (Figure 6), changes occurring in the short distance are related to tectonic processes (i.e. vertical displacement amount resulting at the faulting and uplifting). It is thought that other parameters influencing morphometric indices have secondary effects.

Table 4: Classification of the Iat (relative tectonic activity index) in the study area.

Segment	Drainage basin	Class of Smf	Class of Vf	Class of HI	Class of AF	Class of Bs	S/n	Iat class
Karateke	1	1	2	1	1	2	1.4	1
	2	1	1	2	1	1	1.2	1
	3	1	1	3	3	1	1.8	2
	4	1	2	3	2	3	2.2	3
	5	1	1	3	1	1	1.4	2
	6	1	2	1	3	1	1.6	1
	7	1	1	3	1	3	1.8	2
	8	1	2	1	1	3	1..6	2
	9	2	1	1	2	3	1.8	2
Honaz	10	1	1	1	2	3	1.6	2
	11	1	2	1	1	1	1.2	1
	12	1	1	3	3	3	2.2	3
	13	1	1	3	2	2	1.8	2
	14	3	2	3	3	3	3	4

8 Conclusions

In grabens such as extensional basins in western Turkey including the Denizli Basin that are bounded by normal faults, geomorphic indices are useful tools to investigate the influence of active tectonic deformation. These indices, which are calculated from a DEM are tools to identify geomorphologic anomalies related to possible tectonic activity. In this study, the DEM data of the Honaz Fault were used and indices of triangular facets, drainage basin asymmetry (AF), hypsometric integral (HI), drainage basin shape (Bs), ratio of valley-floor width to valley height (Vf), and mountain front sinuosity (Smf) have been calculated. The relative tectonic activity (Iat) of the study area, which is a combination of the above indices, divides the relative tectonic activity of a landscape into four classes. According to the calculated Iat indice, 19.8% (10.9 km^2), 61.6% (33.9 km^2), 2.8% (1.6 km^2) and 15.8 % (8.7 km^2) of the study area respectively corresponds to class 1, 2, 3 and 4.

Based on these findings, it is concluded that the Honaz Fault has geomorphologically high tectonic activity. These results confirm the usability of morphometric analyses to evaluate regional tectonic activity. However, further detailed studies about tectonics in the study area are necessary. Morphometric studies on the Pamukkale and Babadağ faults, which are other boundary faults of the Denizli Basin, are suggested in order to determine the effect of active tectonics in the region.

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